

A Study on Visual Search during the Trail Making Test: Analysis Using an Eye Tracker

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Abstract

The Trail Making Test A (TMT-A) is a task related to visual search. Therefore, performance in the TMT-A has a high possibility of being influenced by visual information, such as the arrangement of numbers. The purpose of this study was to measure eye movements during the TMT-A using an eye tracker, to analyze differences in enforcement and trace execution, and to examine appropriate inspection drawings as visual search tasks. Study 1 was performed in 14 young healthy subjects and Study 2 was performed in 6 young healthy subjects. The English and Japanese versions of the TMT-A were administered as usual and the subjects performed the traces in a sitting position. The eye movements of the subjects were measured during the task. We analyzed the combined motion angles of both eyes. We compared the average values (30 Hz/s) of movement in the horizontal (X-axis) and vertical (Y-axis) directions during the normal administration of the English and Japanese version of the TMT-A. We also compared the traces performed by the subjects. There were no differences in tracing or enforcement in the English version of the TMT-A. Especially in the vertical visualization operation, it was shown that the normal enforcement was fewer than the tracing, and almost no up-to-down search was performed. In contrast, the subjects performed visual searches in all directions during the Japanese version of the TMT-A.

Keywords

Trail Making Test, Eye Tracker, Attention

1. Introduction

Deficits in high-order brain functions, such as memory disorder, attention dis-

order, and executive function disorders are evaluated using the Wechsler Adult Intelligence Scale, Clinical Assessment for Attention, or Behavioral Assessment of the Dysexecutive Syndrome. The Trail Making Test (TMT) is used worldwide as a test for attention disorder. The TMT was originally a part of the Army Individual Test Battery [1] and was used as a component of the Halstead-Reitan Neuropsychological Test Battery [2]. Several versions of the TMT, such as Reitan's Japanese revised edition (hereafter referred to as the English version) and the Keio version established by Kashima *et al.* Keio university (hereafter referred to as the Japanese version) are used in Japan [3] [4] [5] [6]. TMT inspection procedures are unified, but the inspection paper is not unified.

The TMT consists of two parts. The TMT-A is used to assess the sustainability of attention, while the TMT-B is used to assess selectivity and distribution of attention. The TMT-A in particular involves a visual search task. The score on each part represents the amount of time required to complete the task [7]. Therefore, it is not always possible to selectively evaluate attention using the TMT-A, as performance in this task may be affected by various factors, including visual information. In addition, the numbers seem to be arranged relatively regularly in the vertical direction for several seconds (up to 12) in the English version of the TMT-A, while no such regularity is observed in the Japanese version of the test. Gaze analysis during the TMT would enable us to study whether the TMT-A is a visual search task or affected by factors other than visual search.

Recently, eye tracking has been used to measure eye movements during different activities. Eye trackers are devices that measure the movements of the subject's gaze. These devices project light onto the cornea. The reflection of that light is then used to follow the movements of the eyeball on a screen. It is possible to measure different types of gaze movement to determine the amount of time for which a subject watches an advertisement, among other measures. Eye trackers are thus mainly used in the industry. Nevertheless, eye trackers are also used to analyze gaze during the performance of specific tasks. This in turn enables us to study whether TMT-A is influenced by visual information, such as the arrangement of numbers in illustrations.

The purpose of this study was to measure eye movements during the TMT-A, to analyze differences in normal enforcement and tracing enforcement, and to investigate appropriate inspection drawings as visual search tasks.

2. Methods

2.1. Procedure

In this study, eyeball movements during the English version and Japanese version of the TMT-A, which is widely used in Japan, were measured using an eye tracker. The tests performed using the English version of the TMT-A Comprised Research Study 1. We also used the Japanese version of the TMT-A in an additional study wherein we also measure eye movements using an eye tracker. This additional study was designated Research Study 2. Study 2 was performed after

Study 1 and had different subjects.

The TMT-A English version used in this research refers to a vertically written diagram of A4 size created by Reitan. This figure is widespread in Japan. The English version can purchase inspection paper and manual from Reitan Neuropsychology Laboratory. On the other hand, the TMT-A Japanese version refers to the B4 size horizontally written drawing number created by Keio University, such as Kashima *et al.* In the English version and the Japanese version, the numbers 1 to 25 are randomly arranged in TMT-A, but the positions of the numbers are different.

2.2. Participants

The participants in Study 1 were 14 students (10 men and 4 women, average age: 21 years). Study 2 had 6 subjects (4 men and 2 women, average age: 21 years). All subjects performed the test with the naked eye or had sufficient visual acuity to observe the letters with vision correction. The subjects in Study 2 matched those in Study 1 in terms of age, sex, and the time required to complete the TMT-A (English version). Details of the subjects in Studies A and B are shown in **Table 1**. The exclusion criteria were naked eyes with a visual acuity of 1.0 or less, no consent to participation in the study, extreme fatigue at the time of study participation, and lack of sleep (less than 6 hours).

2.3. Protocols

In Study 1, the English version of the TMT-A was administered with the subject in the sitting position as usual. This way of administering the test was designated “normal enforcement”. The subject was then allowed to rest until the feeling of tiredness had disappeared. Second, the subjects were instructed to accurately trace lines connecting the numbers in the English version of the TMT-A. This task was called “tracing enforcement”. Similarly in “Study 2”, Using the Japanese version of the TMT-A, “normal enforcement” and “tracing enforcement” were carried out. “Trace enforcement” is guided by the trace line to the next number, so there is no need for visual search. Therefore, the sum of the angles of eye movements is minimized. On the other hand, since it is necessary to search for the next figure for “normal enforcement”, the sum of the angles of eye movements should be large as a result of explorative eye movements.

Table 1. Details of the subjects in Studies 1 and 2.

	Study 1n = 14	Study 2n = 6	
Age [†]	21	21	n.s.
Sex ^{††}	10 men and 4 women	4 men and 2 women	n.s.
Time to perform TMT-A (English version) [†]	24.8 ± 7.7 sec	30.6 ± 8.8 sec	n.s.
n.s. = not significant			
† = Student's t-test			
†† = chi-square test			

2.4. Equipment Used

The eye movement measurement system TalkEye Lite (Takei Instruments Co. Ltd, Japan) was used to measure the combined motion angles of both eyes. TalkEye Lite is a wearable eyeball movement measurement system that uses a USB camera for detection of the eyeball and the visual field. This device is connected directly to a processing computer used to measure eyeball movements. We measured the combined motion angles of both eyes using the eye tracker in Study 1 (“normal enforcement” and “tracing enforcement”) and Study 2 (“normal enforcement” and “tracing enforcement”). The average eye movement values (30 Hz/s) during the first 8 seconds of the test in the left-right (X-axis) and up-down (Y-axis) directions were measured.

2.5. Analysis

The average eye movement angles in the horizontal (X-axis) and vertical (Y-axis) directions during the “normal implementation” and “tracing enforcement” tasks were measured and compared (in Study 1 and 2 respectively). Eye movements during the “tracing enforcement” task were the most efficient (less eye movements). This is because the task only requires tracing a line that has already been drawn. We analyzed the first 8 seconds of the task, as all of the subjects had passed through the number 12 by this time, whose regularity is apparently observed in TMT-A English version. We compared the two different tasks using t tests with a significance level of 5%.

2.6. Ethics

Prior to the administration of the tests, a document explaining the purpose of the evaluation was distributed to each subject. After the explanation, subjects who agreed to participate signed the agreement on the consent form. Informed consent was thus carefully obtained from the participants. The study was conducted in accordance with the ethical standards set forth in the Helsinki Declaration (1983). The entire study protocol was approved by the Yamada Hospital Expert Committee on University Research Ethical Evaluation (approval day 2017.11).

3. Results

In Study 1, which used the English version of the TMT-A, the average eye movement angle in the X-axis was $0.882^{\circ} \pm 1.854^{\circ}$ during normal implementation and $0.757^{\circ} \pm 2.634^{\circ}$ during tracing enforcement. In the Y-axis, the mean eye movement angle was $0.688^{\circ} \pm 1.465^{\circ}$ during normal implementation and $0.675^{\circ} \pm 1.886^{\circ}$ during tracing enforcement. We found no significant difference between the 2 groups in either the X- or the Y-axis (**Table 2**). In Study 2, which was performed using the Japanese version of TMT-A, the mean eyeball angle in the X-axis was $1.732^{\circ} \pm 3.506^{\circ}$ for ordinary enforcement and $1.223^{\circ} \pm 3.079^{\circ}$ for tracing enforcement. In the Y-axis, the mean eyeball angle was $1.173^{\circ} \pm 2.815^{\circ}$

during normal enforcement and $0.830^{\circ} \pm 3.618^{\circ}$ during tracing enforcement. We observed significant differences in both the X-axis movements ($p = 0.000$) and Y-axis movements ($p = 0.000$) (**Table 3**).

4. Discussion

Here we measured eye movements during the English and Japanese versions of the TMT-A using the eye movement measurement system. We analyzed differences in eye movements between the “normal enforcement” and “tracing enforcement” tasks (Japanese version and English version respectively). There were no significant differences in eye movements between the “normal enforcement” and “tracing enforcement” tasks in the English version of the TMT-A. In the Japanese version of the TMT-A, eye movements were significantly greater during “normal enforcement” than during “tracing enforcement”.

The most efficient eye movements were observed during “tracing enforcement”. This task requires little visual search because the subject was only required to trace the correct line. There was no significant difference between “normal enforcement” and “tracing enforcement” in the English version of TMT-A, which was administered in Study A. This indicates that there was little visual search in any direction in this test. There was especially little difference between “normal enforcement” and “tracing enforcement” in the vertical direction. This indicates that almost no top-to-bottom search was performed.

In the English version, the characters tend to be arranged continuously from the top to the bottom in the early part of the test, unlike in the Japanese version. The result presented here indicates that no eyeball movements in the vertical direction were. The participants may thus have been consciously or unconsciously aware of the regularity in the English version of the test. However, it is unknown whether participants in this study noticed the abovementioned regularity. Nevertheless, our results indicate that the performing the TMT may involve a strategy other than visual search.

Normally, when a visual search is performed in the TMT-A, the numbers are

Table 2. Comparisons of the average eye movement angles in the English version of the TMT-A.

	normal	tracing	t-value	df	p-value	effect size
X-axis (°)	0.882 ± 1.854	0.757 ± 2.634	1.705	1903	0.088	0.06
Y-axis (°)	0.688 ± 1.465	0.675 ± 1.886	0.234	1903	0.815	0.01

Table 3. Comparisons of the average eye movement angles in the Japanese version of the TMT-A.

	normal	tracing	t-value	df	p-value	effect size
X-axis (°)	1.732 ± 3.506	1.223 ± 3.079	6.561	3593	0.000	0.15
Y-axis (°)	1.173 ± 2.815	0.830 ± 3.618	4.482	3593	0.000	0.11

recognized, the presence of consecutive numbers is confirmed, and the relevant number on the paper is quickly found. The line of sight during the search should thus move both vertically and horizontally. However, there was hardly any vertical eye movement in Study A. This suggests that the participants guessed the position of the next digit based on the regularity of the arrangement of the numbers in the TMT-A without relying on a visual search. This indicates that the TMT does not involve a search task, which is ostentatiously evaluated by the examination. Therefore, the TMT does not fulfill its stated purpose. These results suggest that one should use caution when interpreting the results of the English version of the TMT-A, which has regular number placement.

Normally, when the TMT is performed, the difference between the trial time for part A and that for part B is calculated and indicated as the ratio of the time for part A to that for part B. These offset the other search factors found in TMT-A. However, information gained from the TMT-B is important. As a result, it is not desirable to only perform the English version of the TMT-A. Using the Japanese version of the TMT-A, which does not allow have regularity in the way the numbers are presented, is crucial to eliminate compensatory effects when only the TMT-A is used, as frequently done in the clinic. As indicated by the results of Study B, the Japanese version of the TMT-A requires visual search in all directions, with significant differences between the “normal enforcement” and “trace execution” tasks. This suggests that the Japanese version of the TMT-A can be used as a visual search task. Previous research also stated that the examination time will be prolonged because the layout of the figures is more complicated in the Japanese version than in the English version of TMT-A [8], supporting the fact that the TMT-A Japanese version is suitable as a visual search task.

Currently, searching for “TMT-A” on the web results in a list of various illustrations mainly found in the English and Japanese versions. It is thus difficult to determine the optimal picture. However, the TMT-A, which has strong implications for visual search, is affected by the arrangement of the numbers and letters, and requires in the interpretation of its results. In this research result it is recommended to check the arrangement of numbers and letters of TMT and to use the randomized figures.

5. Limitation

The subjects in this study were healthy students. Therefore, generalization of the results requires caution. Increasing the group size in future studies would enable us to more confidently generalize our findings.

6. Conclusion

In this study, eye movements during the TMT-A were measured using an eye camera. We analyzed the differences between ordinary enforcement and tracing enforcement. There were no significant differences between enforcement and

tracing in the English version of the TMT-A. It was shown that the normal enforcement task required fewer eye movements than the tracing task, especially in the vertical direction, as almost no search was performed in the top-to-bottom direction. In contrast, the Japanese version of the TMT-A required visual search in all directions.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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